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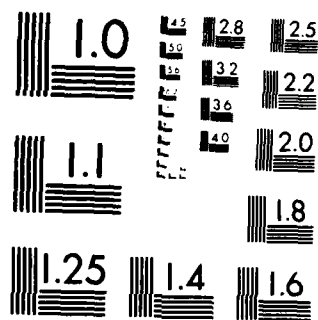
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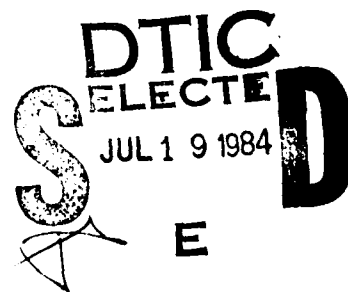
Technical Report 83069

August 1983

## LIFE TESTING OF RUBBER SEALS

by

A. J. Kearse



Procurement Executive, Ministry of Defence  
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SUMMARY

Tests to assess the variation of seal friction and seal life with temperature are described and the results of these tests are presented. Measurements of the pressure distribution under a rubber seal have been made, and the relationship of this to seal performance is considered. Results are discussed with reference to the lubrication properties of different combinations of seals and fluids. Seal condition at failure is also described.



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## 1 INTRODUCTION

Increases in operating temperature and pressure in aircraft hydraulic systems require improved performance from seals. The work in this Report is on dynamic rod seals for aircraft general service actuators. Basic requirements of the seal are that there is no net leakage under static or dynamic conditions, that the friction is low, and that life is adequate for its application, and these should be met over a range of operating speeds, temperatures and pressures ( $-54^{\circ}\text{C}$  to  $135^{\circ}\text{C}$ , 28 MPa).

Tests were carried out to determine the relationship between seal life, friction and temperature at constant stroking speed and pressure.

Seal types tested are shown in Fig 1. The common features are the use of rubber sealing elements and backing rings made of filled plastics. Owing to the dimensions of the rod and gland the seal assembly is retained in interference with the rod even when there is no system pressure applied. Backing rings are fitted to prevent extrusion of the rubber element into the clearance between rod and gland.

## 2 EXPERIMENTAL INSTALLATION

Seals were tested in the rig shown in Fig 2. These were installed in glands which were at either end of the test block. The rectangular section seals were all of nitrile rubber. Tee seals were of two rubbers; a high temperature rubber (PNF) and nitrile rubber. All were of the same size, to accommodate a 31.75 mm diameter test rod. The latter, which does not have a piston, and glands are finished to aircraft tolerances and surface finishes ( $4-8\text{ }\mu$  in CLA). A jack drives the rod under the test seals, this being part of an electro-hydraulic servo system allowing various control methods; the one used for the tests being stroking between set limits with velocity feedback. Sideloads on the test rod are eliminated by a special coupling between the driving jack and test rod. Hydraulic pressure is supplied to the test block from an air-hydraulic intensifier, control of pressure being maintained by an air regulator. The test block is heated by the passage of a heat exchange fluid from a thermostatically controlled heating unit, but the block temperature has to be controlled by varying the rate of fluid flow with control valves. Cooling of the test block is by packing an insulated jacket round the block with Drikold, and preventing the temperature from falling too low by circulating small quantities of fluid from the heating unit.

## 3 INSTRUMENTATION

Force between the driving jack and the test rod is measured by a strain gauged load cell, which is calibrated and temperature compensated. Output voltage is displayed on an oscilloscope.

Temperatures are measured either by thermocouples or by an aircraft platinum resistance element. Thermocouples are inserted into drillings in each gland so that they measure close to the seal assemblies. The block also has a thermocouple and the platinum resistance element to measure the bulk oil temperature. Individual seal temperatures need to be measured close to the seal because the oil bulk temperature does not accurately reflect seal temperature.

An electrical counter is triggered by a microswitch tripped at the end of stroke by the driving jack. The counter thus gives total number of complete strokes since last reset.

#### 4 METHOD OF TEST

Seals were loaded in accordance with the manufacturer's instructions and the usual care exercised over cleanliness in hydraulic systems. The pressurising system was filled with the test fluid, either OM15(OTD585) or Mil-H-83282, the test seals being soaked for 24 hours in the fluid before loading. Dimensional checks were made of the seals before and after loading into the gland. A new rod was used for each test to ensure that surface finish was always consistent.

The experiments were not designed to reproduce a particular duty cycle but to reflect typical stroking speeds and temperatures in a simple test.

##### 4.1 Life tests

The aim of these tests was to establish the life of seals at various maximum temperatures, using a temperature cycle to exercise the seal properties. A balance has to be struck between the severity of the test conditions and the amount of time that can be taken to test the seals at moderate temperatures. The test cycle used was as follows:

- (i) 5000 stroking cycles at high temperature and 28 MPa pressure.
- (ii) Cold soak for 4 hours at low temperature ( $-40^{\circ}\text{C}$ ) and 3 MPa. Raise pressure to 28 MPa and stroke for approximately 200 cycles.
- (iii) At room temperature, 28 MPa, stroke for approximately 200 cycles.

This test cycle was repeated until failure occurred.

Stroking conditions used were: 63 mm stroke, 130 mm/s speed. Leakage, friction, temperature and number of strokes were recorded at each stage. Failure is defined as the point where enough leakage from the seal collects to form a drop from the rod or gland.

When failure occurred the glands were removed and, in some tests, measurements taken with the seals in the glands. The seal assemblies were then removed from the gland and labelled, notes being taken at each stage in dismantling of the condition of the seals, rod and glands.

##### 4.2 Friction tests

The aim of these tests was to measure the friction force between the test rod and seals at different temperatures. Stroke conditions used were the same as the seal life tests. Because the load cell is outside the test block individual seal outstroke and instroke friction cannot be separated. Total force measured is the sum of one seal's outstroke friction force plus the other seal's instroke friction. Seal loading was performed as in the life tests. After heating to about halfway between ambient and the highest test temperature, the rig was stroked until the final desired temperature was

reached. Stroking was done to run in the seal combination and to reduce the temperature overshoot due to frictional heating.

In order to measure friction at a number of temperatures, the seal was heated to the high test temperature and friction measurements made. The heating unit was then switched off and rig stroking stopped. When the glands had cooled to the next desired temperature the stroking was started, friction force allowed to settle and measurements repeated. The stroking was then stopped and the glands allowed to cool and so on until the lowest test temperature was reached, measurements of friction, temperatures and number of cycles were taken at each stage. In addition any interesting factors, such as leakage on the rod, were recorded.

## 5 RESULTS

Results from the tests were collated, analysed and plotted. Variations of results are to be expected and temperatures and friction values quoted are the mean of at least six readings.

### 5.1 Life tests

Results from the life tests are plotted in Fig 3. There is a definite relationship between test temperature and seal life. Most of the tests were with rectangular seals, but the few that were done at high temperatures with tee seals produced longer lives. This is consistent with other tests, which are not recorded in this note because the test conditions were not identical, where tee seals ran for comparable periods without leakage or failure. The PNF rubber does not perform so well as the normal tee seal rubber at the same stroking speeds. Since failure usually occurs following the cold soak part of the test cycle, and since leakage is not normally visible at elevated temperatures owing to evaporation, the resolution on the seal life tends to be 5000 stroking cycles (ie one complete test cycle).

### 5.2 Friction tests

Results from the friction tests are plotted on Figs 4 and 5. Friction measurements were taken when full dynamic friction conditions were established, static friction at the end of the strokes being higher. Testing to measure friction was repeated with new seals to obtain extra data points.

For both fluids the friction with the rectangular section seals was higher than the friction with the tee seals. Friction with Mil-H-83282 fluid was appreciably lower with both types of seals, than friction with OM15 fluid. The friction of the rectangular seals did not vary significantly with temperature, whereas that of the tee seals tended to increase with rising temperature; this was most marked with the OM15 fluid.

## 6 DISCUSSION

Results from the tests can be explored by reference to the properties of the seal and fluid combination. There are three conditions which result in zero measurable leakage: a dry rod where no fluid is carried out under the seal; a wet rod where fluid

carried out under the seal is returned on the instroke; and at high temperatures, a sufficient rate of evaporation of fluid on the rod to prevent formation of a drop. It is to be expected that dry rod conditions would produce higher friction and wear than wet rod conditions. Dry conditions can be produced on the instroke if fluid is carried out on the outstroke but the evaporation rate is high. Smoking that was observed on some of the high temperature tests can be inferred to be fluid on the rod, although it is not possible to determine whether this is genuine leakage or merely a lubricated rod (where the fluid will be returned on instroke) without the room temperature test. Failure usually occurs at low or room temperature. This is expected as the mechanism of lubrication is elastohydrodynamic and the greatest film thickness (and greater leakage) occur with higher viscosity oil, that is, at low or room temperature.

#### 6.1 Seal life

Seal failure has been defined as the point in the test cycle when enough leakage collects on rod or gland to form a drop. Both fluid and seal type influence the lives obtained and the sealing characteristics. Much valuable information can also be gained from a study of seal condition at failure.

##### (a) OM15, rectangular seals

Most life tests were conducted with this combination. The rod ran wet up to about 50°C, considerable smoking occurring at high temperature accompanied by the evolution of large amounts of rubber and plastic debris. Machining marks were still visible on the inside diameter of the rubber element at failure and the low pressure side of the rubber element was usually heavily nibbled. It was concluded that compression set had taken place, although the seal assembly had not lost interference with the rod completely. Outer backing rings were normally badly worn, misshapen and smeared towards the air side. Failure of the seals was due to a combination of mechanical damage to seal and backing rings and compression set.

Blackening of the chrome finish on the rod occurred on these tests and appeared to be due to carbon black from the seals. It is probably due to very high temperatures at the seal contact resulting from energy dissipated overcoming friction at the seals.

##### (b) OM15, tee seals

This combination runs wet up to about 90°C, smoking occurring above this temperature. The tee seals have about twice the life, under the same conditions, as rectangular seals. Normal rubber tee seals perform better than PNF tee seals, which show a lack of mechanical strength leading to nibbling of the rubber element. One of the tests with PNF rubber was repeated at 80% stroking speed to confirm this lack of strength, and the seals had much less damage at failure. Normal rubber tee seal elements suffered no damage in the tests, damage being confined to the outer backing ring of the combination. The inner backing ring was normally undamaged or only slightly extruded. Replacement of badly misshapen outer backing rings was found to restore sealing function.

## 6.2 Seal friction

The changes in seal friction values measured seem to reflect quite well the lubrication conditions under the seals, with different seal and fluid combinations. Variation in friction values will occur outside the range explored in the tests and some values at low temperature are mentioned although these are taken from the seal life tests.

### (a) OM15 fluid, rectangular seals

At high temperature the seals appear to be unlubricated on both strokes, and seal friction remains roughly constant over the temperature range covered. In the low temperature part of the seal life test cycle the seals are lubricated and friction forces are in the order of 700 N.

### (b) Mil-H-83282 fluid, rectangular seals

At high temperatures the seals are lubricated by a film of oil on the rod, and the seal friction remains roughly constant over the temperature range covered. Friction with Mil-H-83282 is about a quarter of the value measured with OM15, this being due to the lubricated conditions of the seal. It is probable that the higher friction obtained with OM15 is due to its quicker evaporation at the outstroke thus leading to a dry instroke. Mil-H-83282 does not evaporate so quickly at the same temperatures.

### (c) OM15 fluid, tee seals

Up to about 100°C this combination runs with a wet rod. Above 100°C evaporation is sufficient to produce a dry rod, and friction increases. Friction with tee seals is about one third that with rectangular seals under the same conditions. The changes in friction observed during the tests is reflected in this wet/dry running, the decrease in friction being accompanied by the appearance of fluid on the rod. Below 100°C the friction gradually decreases until about 80°C, below which it remains constant. It seems likely that friction reductions between 100°C and 80°C are due to the gradual establishment of full fluid film lubrication. Friction forces at -40°C are about 600 N.

### (d) Mil-H-83282 fluid, tee seals

The seals are lubricated at high temperature and the seal friction remains roughly constant over the temperature range covered. Friction is about two-thirds of that with rectangular seals under the same conditions.

## 6.3 Test with instrumented jack rod

As part of seal investigations carried out at the RAE<sup>1</sup> an instrumented jack rod capable of measuring pressure distribution and, for an electrically conducting seal, oil film thickness, has been developed. In this case only pressure distribution could be obtained. Rectangular rubber seals have been examined before by this method<sup>2</sup>, but not a tee seal, and an oscilloscope trace showing the pressure distribution is shown in Fig 6, with the interpretation and calibration in Fig 7. A point worthy of note is that the air side backing ring is responsible for most of the pressure drop, this presumably being the cause of most of the damage in these seal combinations occurring at this ring.

#### 6.4 Nibbling

Nibbling has been seen on most of the rectangular rubber elements used in tests. It has also been seen on PNF rubber tee seals. Nibbling is the term given to removal of the rubber material by mechanical damage and requires both system pressure and stroking. The accepted mechanism is that seal material, distorted by pressure into the gap between rod and gland, is pinched off by stroking action, that is, on outstrokes. However, examination of the outer backing ring shows considerable extrusion into the gap (aided by stroking action) which means that the outer backing ring must be in close contact with the rod. This means that there is no gap into which the rubber element can be forced. We therefore require an alternative explanation of the mechanism of nibbling.

At the test temperatures, with OM15 fluid, the rod runs dry on the instroke. Because of the dry rod the instroke friction is higher than the outstroke. The friction forces act on the inside diameter of the seal and try to roll it in the groove, thus concentrating wear at the outside, or air side. It seems likely that, as in the tee seals, most of the pressure drop occurs over the outer edge of the rubber element and the outer backing ring. Further evidence is supplied by the condition of some of the PNF tee seals. These seals had been run at about 135°C, under the normal stroking conditions. Upon dismantling the seals were heavily nibbled on the face of the upright of the tee. The top, or wearing surface, of the upright had been smeared back towards the oil side, against the pressure gradient.

Therefore it seems most likely that nibbling damage is occurring due to high friction on the instroke caused by dry rod conditions, and the loading of the seals at the same end.

#### 7 CONCLUSIONS

The layout and use of a seal test rig has been described. Tests described are mainly to assess the relationship of seal life and seal friction to temperature. A test to measure the pressure distribution under a seal is also described. Two types of seals and two fluids have been used in the tests, and the results have been discussed with reference to the lubrication properties of different combinations of seals and fluids. Seal condition at failure has also been discussed.

Seal life decreases as temperature increases. Seal design and materials and fluid type also influence life. Friction shows little or no variation with temperature, over the range explored, for the rectangular seal, but increases with temperature in the case of the tee seal, particularly when using OM15 fluid. Friction also varies with the seal/fluid combination.

Seal failures have been due to a combination of mechanical damage to the seal rubber elements or backing rings or both, and material changes in the rubber element.

REFERENCES

- | <u>No.</u> | <u>Author</u>  | <u>Title, etc</u>   |
|------------|----------------|---|
| 1          | L.E.C. Ruskell | Reynolds equation and elastohydrodynamic lubrication in metal seals.<br>Proc. R. Soc. A349 (1976)                           |
| 2          | L.E.C. Ruskell | The elastohydrodynamic performance of low-friction, zero leakage metal seals.<br>J. Mech. Engng. Sci., <u>21</u> , 4 (1979) |

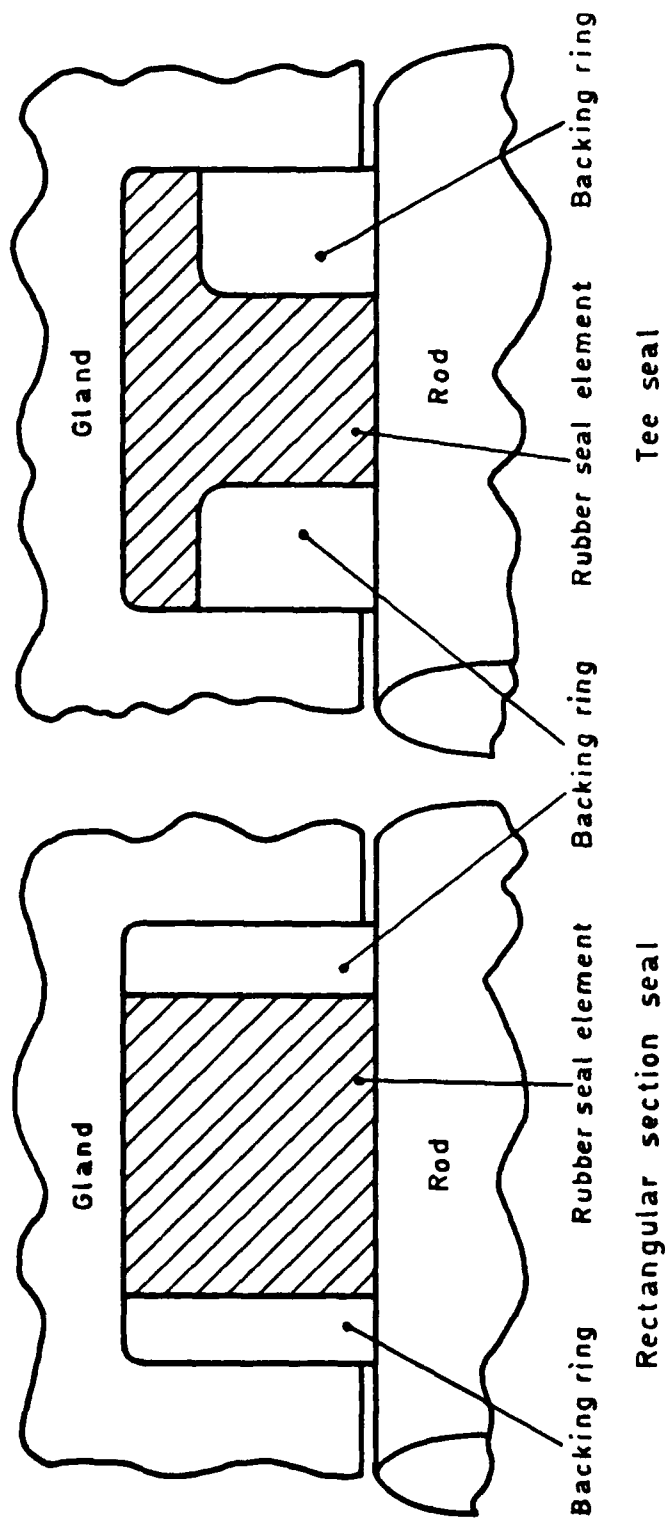


Fig 1 Seal types tested

Fig 2

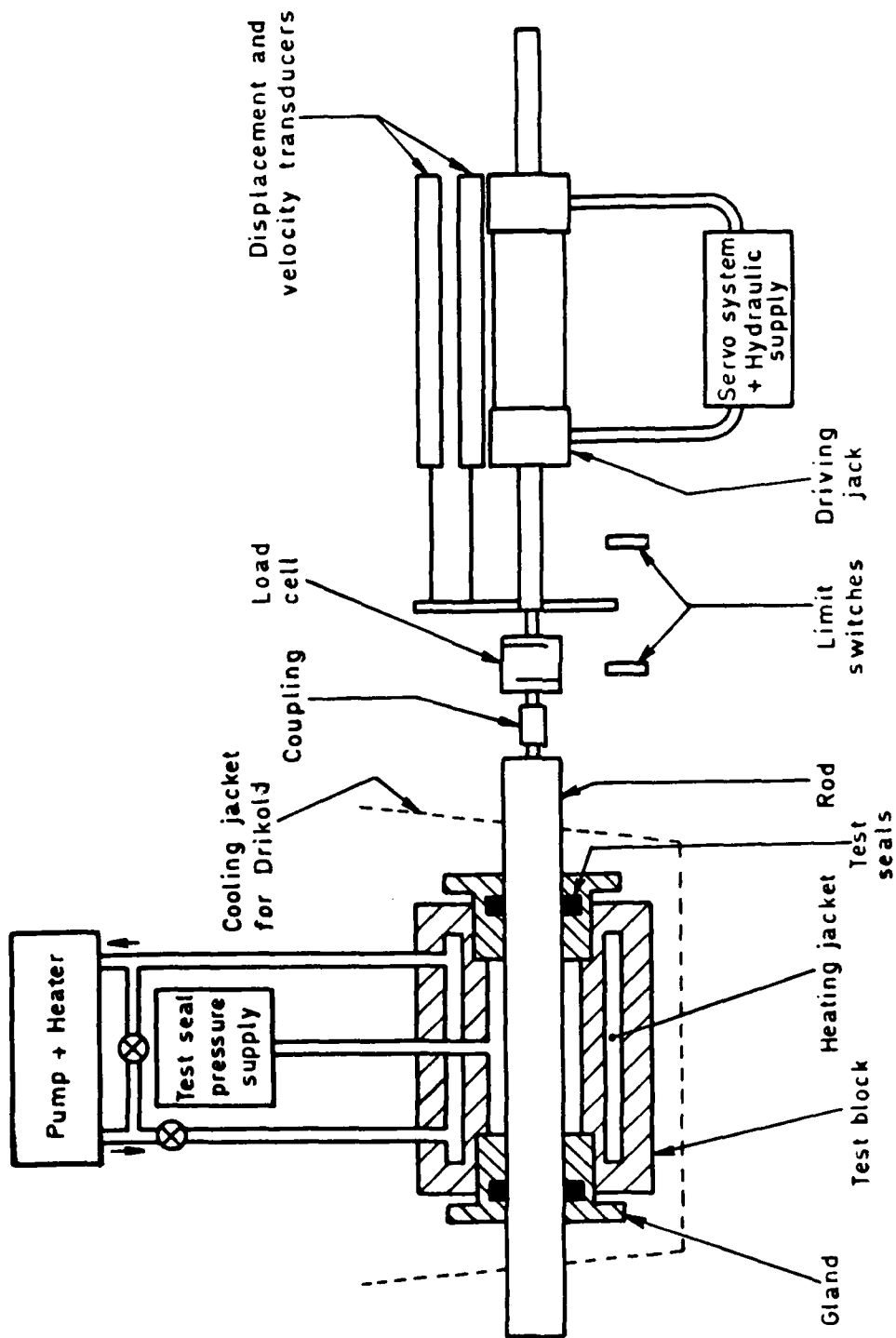


Fig 2 Schematic of seal test rig

Fig 3

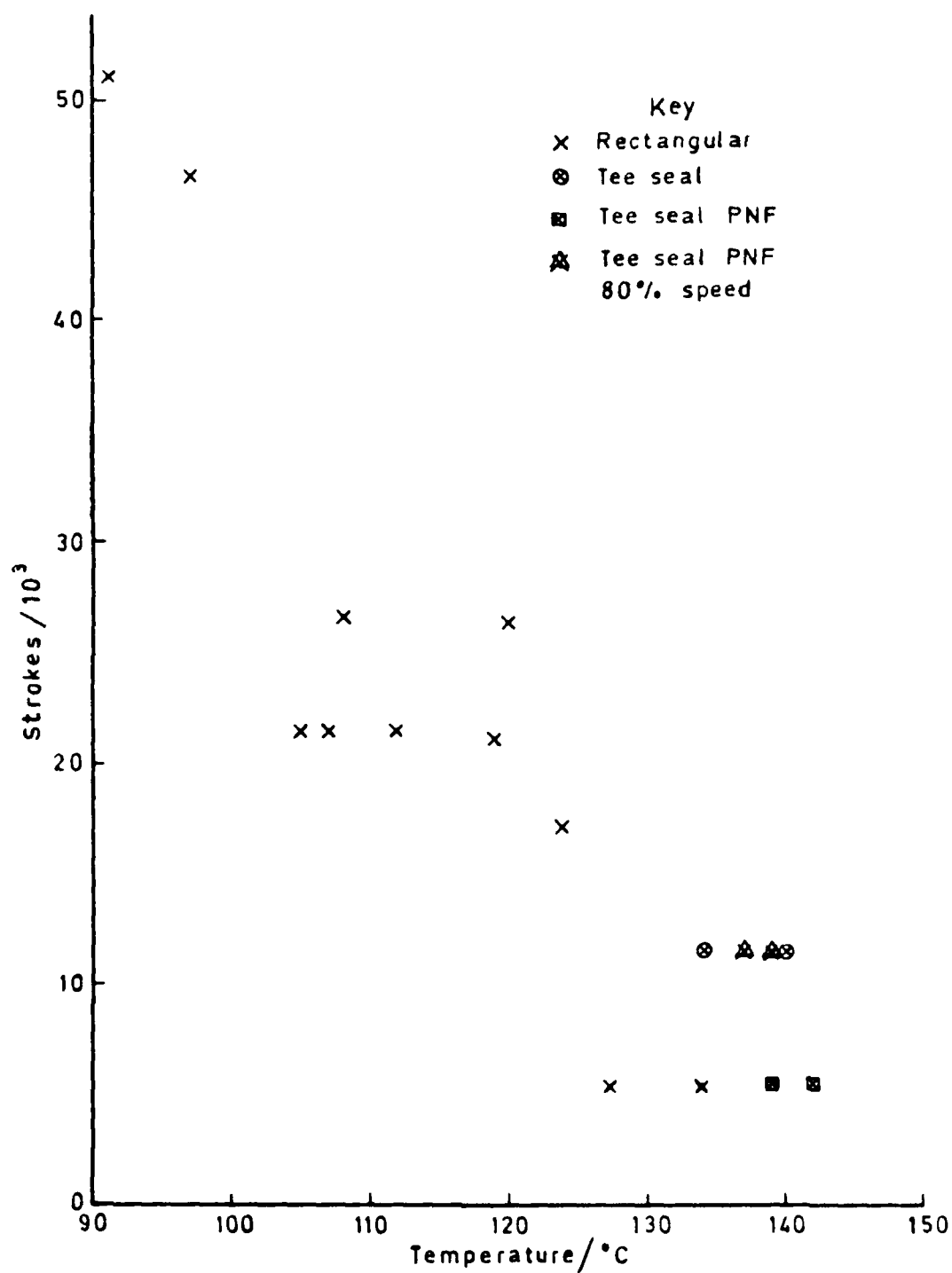


Fig 3 Seal life vs. temperature (OM15 fluid)

Fig 4

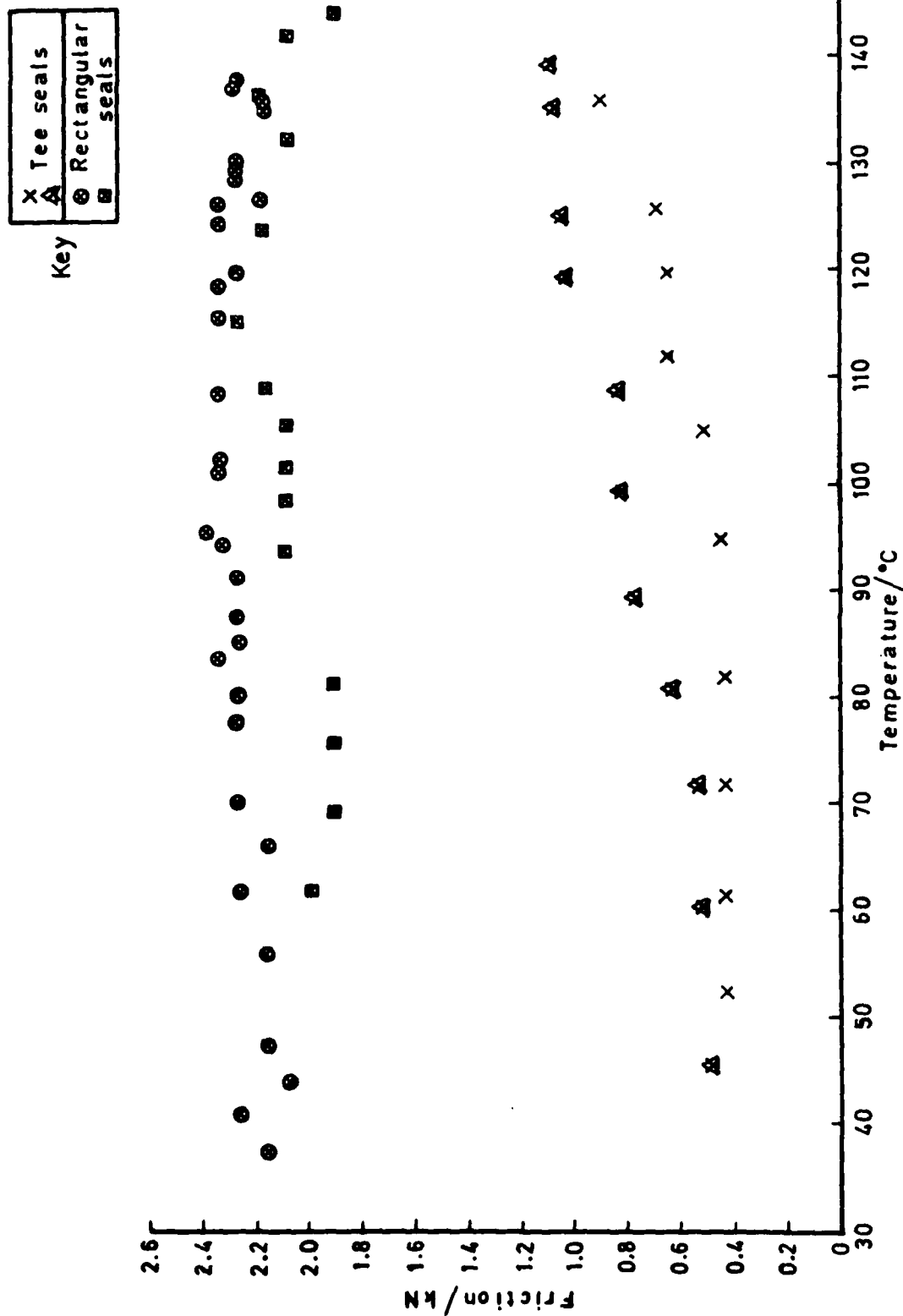


Fig 4 Friction vs. temperature - OM15 (DTD585) fluid

Fig 5

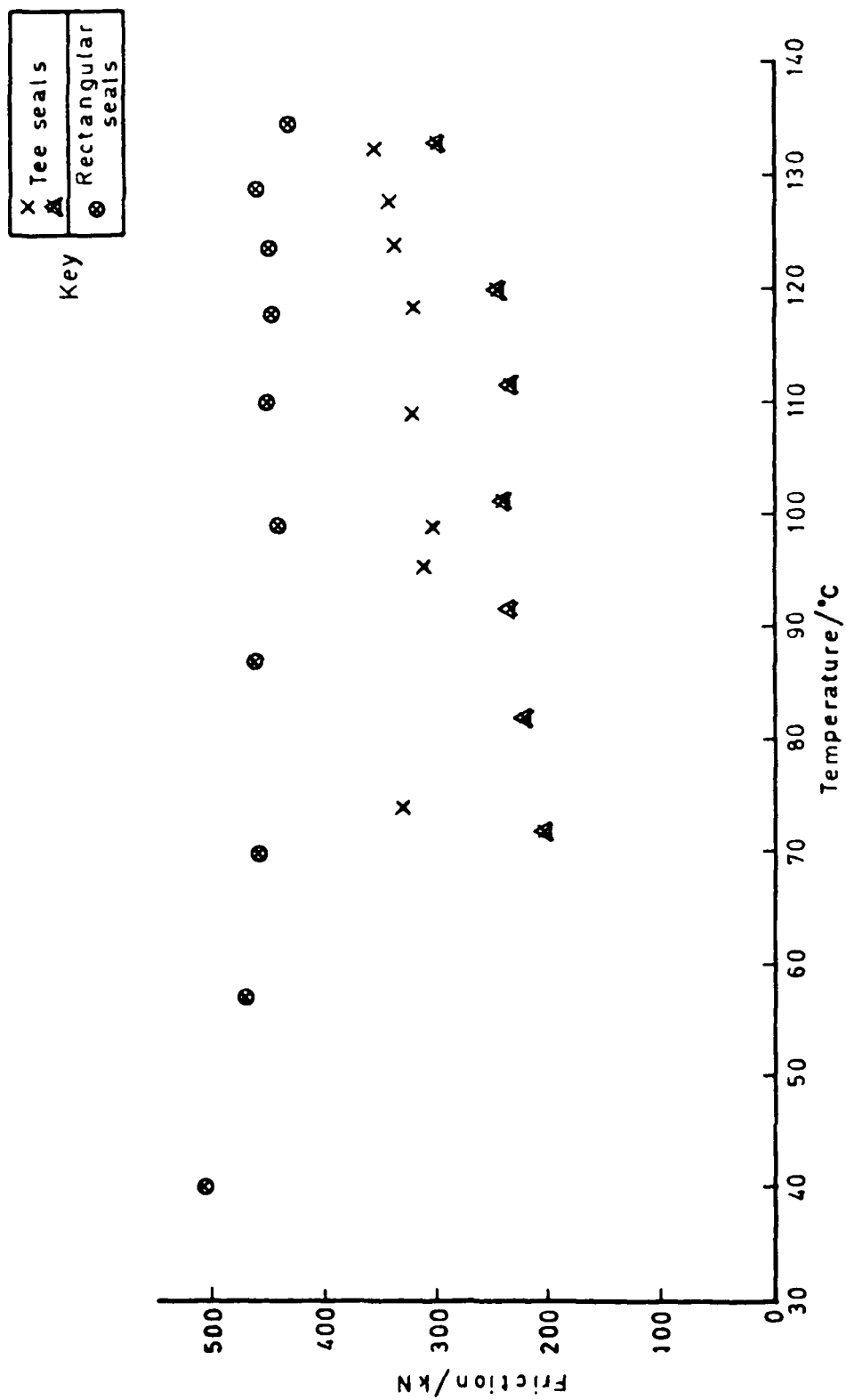


Fig 5 Friction vs. temperature -- MIL-H-83282 fluid



Fig 6 Oscilloscope trace of pressure distribution under tee seal

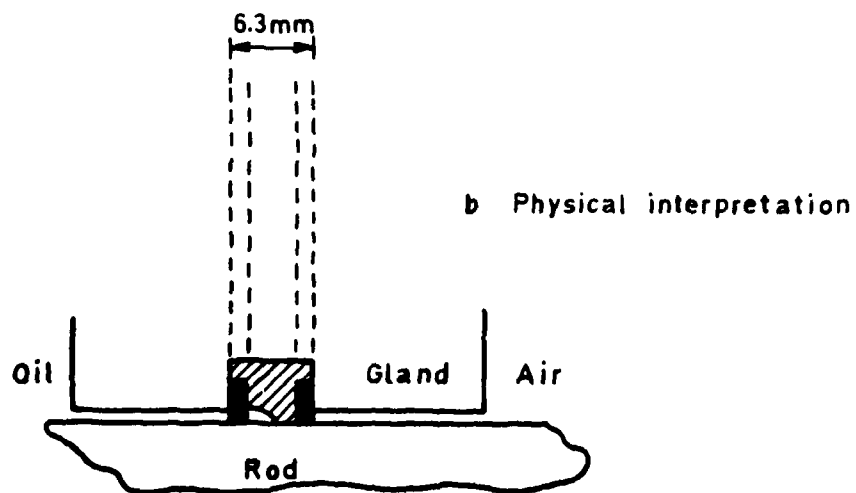
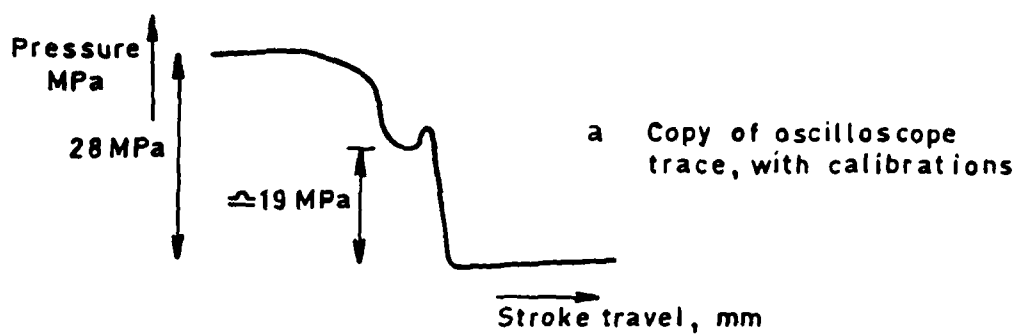


Fig 7 Physical interpretation of pressure distribution under tee seal

# REPORT DOCUMENTATION PAGE

Overall security classification of this page

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17. Abstract  Tests to assess the variation of seal friction and seal life with temperature are described and the results of these tests are presented. Measurements of the pressure distribution under a rubber seal have been made, and the relationship of this to seal performance is considered. Results are discussed with reference to the lubrication properties of different combinations of seals and fluids. Seal condition at failure is also described.					

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